LIFE CYCLE PRODUCTIVITY MODEL
ALSEA RIVER BASIN, COASTAL OREGON

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INTRODUCTION

Spatial processes are an important part of salmon population dynamics (Kocik and Ferreri 1998). Traditional population dynamics models treat salmon populations as large units with assumptions of random mating and with density effects operating on the population as a whole. The term 'population' typically refers to fish within whole basins (e.g., Skagit River) or even several aggregated basins (e.g., Oregon coastal natural coho). Chinook salmon populations are often separated by breeding timing (e.g., Spring or Fall) within a basin. These divisions are convenient, because salmon spawner escapements are usually monitored in this context, and much has been learned about salmon population dynamics at this level of resolution. In our current modeling activities, we are attempting to evaluate effects of freshwater and marine habitats on population status and extinction risks. When we model populations at fine scales within a basin we find that our understanding of population dynamics and risks depends on our assumptions about spatial and temporal population structure. Our present analyses are confined to spatial issues.

Nickelson and Lawson (1998) described a coho salmon life-cycle model based on production in relatively small units of freshwater habitat. It operates with a very fine scale at which populations are defined. The population unit in the Nickelson/Lawson (N/L) model is the "reach", which is defined as approximately 1.5 km of stream length. Each population is independent of all other populations, except that every reach is equally connected to every other reach through the mechanism of random straying of spawners. This model responds to simulated cycles in marine survival differently from single population models. Specifically, the risk of extinction is related to the distribution of spawners within a basin, as well as the abundance of spawners. In the model, distribution of coho, salmon changes on a longer time scale than abundance.

Our current effort is to render the N/L model in a spatially explicit context, enabling us to relax the assumptions of uniform random straying and independent reach-level populations. A primary goal is to explore how fish distribution and straying, patterns of land use, freshwater and marine environmental change, and fish harvest can potentially affect population viability.

Current work has involved discussions and collaboration with Oregon Dept. of Fish and Wildlife (ODFW), U.S. Forest Service (USFS) - Pacific Northwest (PNW) Research

Station, and Sustainable Fisheries Division, National Marine Fisheries Service (NMFS) NW Region. Continued work will possibly include collaboration with University of Washington researchers, U.S. Fish and Wildlife Service (USFWS), and the Comprehensive Chinook forum (state and tribal co-managers in Puget Sound).

This model is applicable within resource management and Endangered Species Act (ESA) recovery planning processes. It should be an aid to broader scope tools of the Cumulative Risk Initiative (CRI) matrix model (Kareiva et al. 1999, and Marvier 1999) and the habitat assessment method described by Bilby et al. (1999). We expect that this model will aid in the evaluation of cumulative effects of land use actions (restoration, development, harvest, etc.) on the viability of salmon populations. We are also exploring how to model future conditions in the context of the effects of large scale climate changes on freshwater and marine survival.

Alsea River Basin

We are working with coho salmon in the Alsea River basin (on the Oregon Coast) using available detailed habitat data and juvenile and spawner coho salmon distribution data. Results from many studies of coho salmon early life history permit us to derive model parameters. We expect to be able to adapt the model to other river basins, other regions in the Pacific NW, other salmon species, and across multiple basins within a region.

The Alsea River drains approximately 1225 kM2 and empties into the Pacific Ocean at Waldport. There are 4 major sub-basins: Drift Creek, Five Rivers, South Fork Alsea River, and North Fork Alsea River.

The coho salmon lifecycle productivity model is designed to operate on the scale of "river reaches". The entire basin was divided into 1400 river reaches of approximately. 1.5 km length. For this analysis we aggregated reach-level data into 6th field Hydrologic Unit Codes (HUCs, see http://civil.ce.utexas.edu/prof/Maidment/gishyd97/library /websites/hucdoc.htm or http://water.usgs.gov/GIS/huc.httnl). The Alsea River basin is comprised of 59 6th field HUCs.

METHODS

Data

We have used existing spatial data, stream habitat data, and coho population data in our model. Most physical data are categorized at the reach level. The stream habitat and coho population data were obtained from ODFW and USFS. The 10 in Digital Elevation Model (DEM) and other spatial data were obtained from the Coastal Landscape Analysis and Modeling Study (CLAMS), at the USFS PNW Research Station

A spatial representation of the Alsea River basin was developed from a DEM using GIS processing in GRASS (see http://www.bayor.edu/~grass). GRASS was then used to create stream vectors and assign GIS spatial data coverages to points in the watershed system. We developed a river network with direction of flow from headwater tributaries to lower river mouth. We used data from the DEM and ODFW habitat and productivity data to assign productivity parameters to each reach. The life cycle model was then based on these productivity parameters.

Estimating Freshwater Productivity and Capacity

Our first task in developing a spatially explicit life cycle model was to estimate both coho productivity and coho smolt capacity parameters for each of the 59 6^{th} field HUCs in the Alsea River basin. These parameters were first calculated for each of the 1400 river reaches, and then aggregated for all reaches within a HUC by summing the capacity and calculating a weighted average of productivities. The productivity (p) and capacity (c) parameters were calculated using the methods described by Nickelson (1998) in his Habitat Limiting Factors Model (HLFM, Version 5.0).

Straying

We use "straying" in terms of location of spawning and adult spawners returning to the reach or HUC from which they originated. Thus, straying is expressed as a rate between pairs of HUCs. Two parameters determine this rate; one (a) is related to the size of the receiving HUC, and a second (b) is related to the distance between originating and receiving HUCs. The equation is:

strays (i, j) = a * (Size(i)/MaxSize) * (I - (Dist(ij)/b * MaxDist)))

where i = destination HUC,
j = source HUC,
Size = area of HUC,
MaxSize = area of largest HUC,
Dist = distance between HUCs,
and MaxDist = the maximum distance between any two HUCs.

Model Runs

Here we present preliminary results from three analyses examining potential recovery patterns of the Alsea River coho salmon population: 1) comparison of single and multiple populations, 2) sensitivity analysis of marine and freshwater survival, and 3) sensitivity analysis of straying.

To examine the recovery pattern of the modeled salmon population, we introduced a cyclic pattern of marine survival: 10 generations (30 yrs) of good marine survival (0.055) followed by 10 generations of poor marine survival (0.0275) followed by 30 generations of high survival. The last 30 generations of high survival were included to give the populations time to stabilize. Runs were initiated with 10 spawners per HUC. A constant harvest rate of 0.5 was used. Freshwater survival is computed by multiplying egg to parr survival and overwinter survival rates. Overwinter survival is constant in each HUC, and is determined by the productivity (p) and capacity (c) values. Egg to parr survival is a function of percent seeding and, therefore, is related to capacity, and number of spawners, which varies each generation.

To examine the differences between a single and a multiple population model, two runs were designed. The single population approach used one set of freshwater p and c parameters (i.e., aggregated for the entire basin by summing c's and using weighted averages of p's from the 59 HUCs), and assumes that spawners return to the basin and distribute randomly. The multiple population approach used the calculated p and c parameters for each of the 59 HUCs, and incorporates straying of the returning spawners between the HUCs.

To explore the sensitivity of changing the freshwater and marine survival rates on the output of spawning abundance in our model, we made model runs which varied the marine survival from 0. 1 to 1. 5, in increments of 0. 1, and varied the overwinter survival rate from 0. 1 to 2.0, in increments of 0. 1.

Again, the amount of straying between HUCs is dependent upon the distance between the two HUCs, and the size of the receiving HUC. To examine the sensitivity of the population to straying, stray distance and stray level were varied, in addition to the varied marine and freshwater survival rates as described above. Straying distance was varied from 0. 1 to 2. 0 in increments of 0. 1, and straying level was varied from 0. 1 to 2.9 in increments of 0.1.

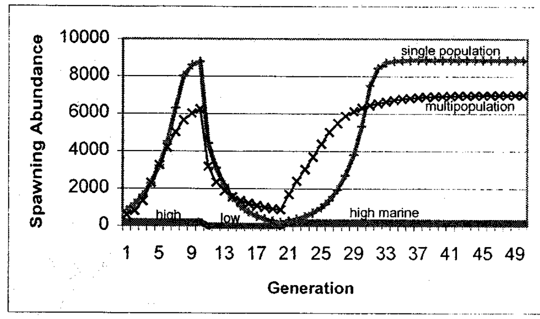
The normal values of the straying parameters result in about 10% of the entire spawning population straying from one basin to another. Using the lowest factor of 0. 1 for both straying parameters results in virtually no straying and using the highest factors of 2.0 for straying distance and 2.9 for straying level results in about half of the population straying.

RESULTS AND DISCUSSION

Comparison of single and multiple populations

The single population model estimated a higher stable spawning abundance for the Alsea River basin than the multiple population model. However, recovery of the single population following the years of low marine survival was slower than that for the multiple population (Fig. 1). Through straying, in the recovery phase in the multipopulation approach, adult spawners can move into areas where coho salmon were extirpated during years of low ocean survival. Thus they more quickly increased the average productivity and capacity for the basin than in the single population approach. In generation 20, i.e. end of the low abundance cycles (Fig.1), only 46 of the 59 HUCs were still populated. At the start of the multiple population runs all HUCs were seeded with a low spawning level of 10 adults per HUC. Since all of the HUCs were populated, the recovery from this low level was more nearly the same at the start of the single and multiple population runs than for the recovery starting in generation 21 (Fig 1).

Figure 1. Comparison of estimated adult spawner abundance for Alsea River coho salmon using a single population approach versus a multipopulation approach. The bottom line indicates periods of high and low marine survival.

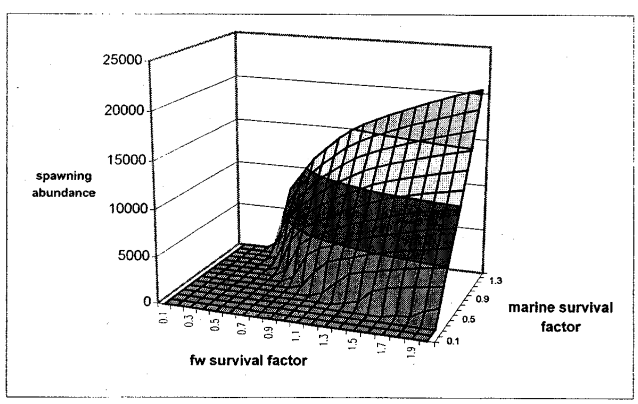


After recovery and during periods of high abundance all 59 HUCs were re-populated through straying. The productivity and capacity of each HUC differs, and many HUCs have relatively low p and c values. Thus, spawning adults frequently strayed into less productive areas and the estimated maximum population level was less than that estimated by the single population model (Fig. 1).

Sensitivity analysis of marine and freshwater survival

Figure 2 illustrates final spawning abundance (generation 50, Fig. 1) for a range of freshwater and marine survival scaling factors. As expected, when both marine and freshwater survivals are high, the spawning population is greatest (Fig. 2). However, it is interesting to note how quickly the abundance dropped off when either ocean or freshwater survival parameter was decreased and how many combinations of low survival resulted in zero population levels. It should also be noted that the current estimates of survival, indicated by factor I for both survival parameters in Fig. 2, give an abundance of 7,000 spawners, which is close to the edge of a rapid drop off in abundance in the plotted 3-dimensional surface (Fig. 2). This indicates that the population would not survive much additional decrease in survival.

Figure 2. Spawning abundance at the end of 50 generations for the multiple population model for a range of freshwater and marine survivals.



Sensitivity analysis of straying

When the stray level (related to amount of straying) and the stray distance (relates to how far adults stray) are both increased, the spawning abundance increases. Conversely, when the two parameters are both decreased, the abundance decreases (Fig. 3). For reference, the abundance at factors of I for both straying parameters is 7,000 spawners.

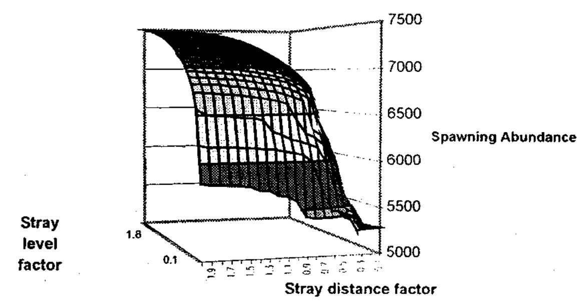


Figure 3. The spawning abundance at the end of 50 generations for the multiple population model for a range of values for the two straying parameters. The base level values for freshwater and marine survival were used (i.e., factor of 1).

When survival was reduced, we saw a noticeably different effect from increased straying (Fig. 4). High rates of straying resulted in the decimation of the spawning population due to fish straying into relatively unproductive areas. However, there is a large platform of relatively stable abundances for a wide range of stray parameter values. In Fig. 3, the abundance at the point of both stray factors being I lies near the right edge of the plateau, such that decreases in the factor of both parameters resulted in reduced abundance, but a moderate decrease in one and increase in the other resulted in the abundance not changing much. At reduced levels of survival, large rates of straying caused the spawning population to become too dispersed to maintain the population.

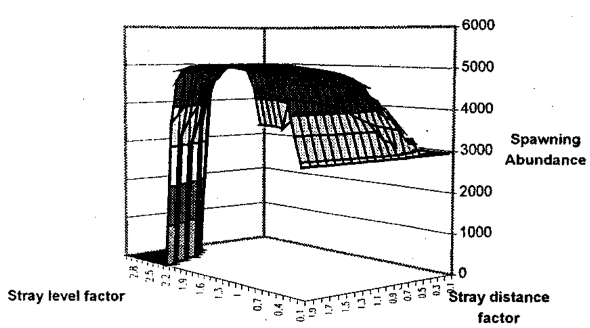


Figure 4. The spawning abundance at the end of 50 generations for the multiple population model for a range of values for the two straying parameters when the base marine and freshwater survival have both been reduced to 0.9 of their value.

LITERATURE CITED

Bilby, B., G. Pess, B. Feist, and T. Beechie. 1999. Freshwater habitat and salmon recovery: relating land use actions to fish population response. Unpublished manuscript. Presented at CRI Workshop, September 1999. Available from NMFS-NWFSC, 2725 Montlake Blvd. E., Seattle, WA 98112.

Kareiva, P., M. Marvier, M. McClure, P. McElhany, M. Ruckelshaus, B. Sanderson, and R. Waples. 1999. An introduction to NMFS decision-support science for ESA decision making, with examples. Unpublished draft manuscript. Presented at CRI Workshop, July 1999. Available from NMFS-NWFSC, 2725 Montlake Blvd. E., Seattle, WA 98112 or from web site: http://www.nwfsc.noaa.gov/.

Kocik, J.F., and C. P. Ferreri. 1998. Juvenile production variation in salmonids: population dynamics, habitat, and the role of spatial relationships. Can. J. Fish. Aquat. Sci. 55(Suppl. 1): 191-200.

Marvier, M. 1999. Estimation of Parameters for Seven Index Stocks of Snake River Spring/Summer Chinook Salmon. Unpublished draft manuscript. Available from NMFS-NVYTSC, 2725 Montlake Blvd. E., Seattle, WA 98112 or from web site: http://www.nwfsc.noaa.gov/.

Nickelson, T.E. 1998. A habitat-based assessment of coho salmon production potential and spawner escapement needs for Oregon Coastal streams. Information Rpt. 984. Oregon Dept. of Fish and Wildl., Fish Div., Portland.

Nickelson, T.E., and P.W. Lawson. 1998. Population viability of coho salmon, *Oncorhynchus kisutch*, in Oregon coastal basins: application of a habitat-based life cycle model. Can. I Fish. Aquat. Sci. 55: 2383-2392.